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CHANNEL ACCESS ARBITRATION FOR AMSAT PHASE 3 PACKET RADIO

by
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This paper discusses possible schemes by which access to the packet radio channel(s) on AMSAT Phase 3 can be efficiently shared between users.

MODEL OF USE

Based on the satellite packet radio meetings held in conjunction with the AMSAT General Meeting in October 1982, it appears that the packet radio channel(s) on Phase 3 will be used by gateway stations for linking terrestrial packet radio networks. Thus the number of stations contending for access will be comparatively small. The traffic may be either interactive, or complete messages such as computer files. Though it exacerbates the problem, it is assumed here that the gateway is not aware of the use (interactive/message) of a particular packet which it is handling. It is expected that the satellite circuit between two terrestrial packet networks may be simultaneously shared by a number of users. Based on expected signal strengths and equipment availability, signalling rates of 400 and 1200 bauds are expected.

Most of this discussion assumes that the terrestrial stations cannot listen while they transmit; ie. collision detection is not possible. The transmit to receive (and vv.) turn-around time for the terminal equipment is a parameter of this analysis.

The propagation path delay from the sender to the receiver will vary from a few milliseconds up to about 260 ms. It will be greater than 180 ms most of the time. A value of 260 ms is used in this analysis.

Systems Parameters

Propagation path delay	260 ms
Transmit-receive (or vv) switching time	50, 100, 200, and 400 ms
Data rate	400, 1200 bits per second
Packet header/trailer	100 bits total
Packet total size	1000, 2000 bits

ACCESS ARBITRATION SCHEMES

WARNING: FOLLOWING COMMON PRACTICE, THE THROUGHPUT QUOTED HERE INCLUDES ALL HEADER BITS, EVEN THE PREAMBLE FOR SYNCHRONIZATION. THE USEFUL THROUGHPUT IS THEREFORE CONSIDERABLY SMALLER.

ALOHA

The simplest scheme is certainly ALOHA, in which a station desiring to transmit does so, without first checking to see that the channel is free. This simplicity is balanced by low throughput. Since transmissions must be repeated if they are destroyed by others, offering additional load actually decreases

useful throughput. The maximum possible throughput is 1/2e, about 17%, of the raw bit rate.

Slotted ALOHA
If stations are constrained to start sending only at specific times, and these times are one packet apart (one slot), a collision can only destroy one packet, rather than overlapping two. The ultimate throughput is thus about 36%, with maximum length packets. It becomes poorer if the packets do not fill the full slot time. Starting time at all stations must be synchronized to a small fraction of a slot duration, perhaps to a few milliseconds.

Carrier Sense, Multiple Access
One might expect more efficient use of the channel would occur if it were checked for occupancy before transmission was initiated. Analysis by others [KLE75][SHE78] has shown that this is indeed true, IF the propagation delay is short compared with packet duration. In fact, the critical parameter is not the just the propagation delay, but the total uncertainty time between the last time that transmission from another station could be sensed and the time when the local station's transmitter output begins. This is the sum of the propagation delay and the receive-transmit switching time. Let "a" be the ratio of the uncertainty time to the packet duration. Curves given by Sherman, et al, [SHE78] indicate that, if "a" is greater than about 0.7, the various CSMA schemes give worse thoughput that plain ALOHA. Non-persistent CSMA (Op-CSMA) seems best suited to the amateur satellite application, since it handles large overloads in offered load better than the other simple CSMA, one-persistent. In non-persistent CSMA, each station listens before transmitting. If the medium is busy it defers for a random time and repeats the process. An improved scheme, suggested by JE Malcolm of NBS and also at INRIA in France, where it is used in their "Danube" local area network, is to run the timers only when the medium is NOT busy. Thus timers never expire when the medium is occupied, and their effective value is increased to spread load when there is a great deal of offered load. The backoff timers can be set to small values. This technique is not included in the following data.

For 0-p CSMA to be better than Slotted ALOHA, "a" must be less than about 0.28. There is thus a substantial benefit to keeping the number of bits "on the fly" small - by keeping TR-switching time short. Calculations based on Sherman's curves show that relative throughput decreases slower than bit rate increases when going from 400 to 1200 buts per second under the conditions assumed in this paper, thus there is a net increase in information throughput by going to the higher bit rate. An improved non-persistent

Token Passing
The Token Bus (TB) proposal being considered in IEEE standards project 802 provides a means to arbitrate a broadcast medium without data packets suffering collisions. A token, granting permission to use the medium, is passed among all stations which may wish to use the medium. Only the station actually in possession of the token is allowed to use the medium. Adding and

removing stations, and recovery from lost or duplicate tokens is handled automatically, at VERY considerable processing expense. It appears likely that some, or most, of this arbitration scheme will be implemented in large scale integrated circuits in the near future. The chips made for Datapoint's ARCnet by SMC do not appear to conform with this proposed standard. ARCNET, as recently described in Electronics magazine, uses as very inferior technique for letting stations join and exit, and for handling token loss (all possible addresses are polled!). It is interesting to note that Radio Shack has signed up to use ARCnet.

Since once a station has the token there is essentially no chance of packet loss through collision, transmission of as much information as possible should be accomplished to keep efficiency up. All data on hand should be transmitted, to all distant station stations possible, to the full extent allowed by the protocol window size. If only a few of the stations in the token passing logical ring actually have data to send, efficiency suffers.

It is assumed that the processing, at each station, to pass the token is 1 ms. The time to pass the token from one station to the next is approximately the propagation delay plus the token duration plus the R-T switching time plus the calculation time. The token duration would be the minimum packet duration, say 100 bits including header. The calculated values of throughput assume that, on average, 1000 or 2000 bits of packet are transmitted for each station in the token passing logical ring. It is not important which of the the stations actually transmit the information.

The accompanying figures show that, while the relative throughput is lower at 1200 bits per second, the ratio is less than the ratio of bit rates.

LDDI (CSMA-CP) Arbitration
ANSI standards committee X3T9.5 has produced the Local Distributed Data Interface (LDDI) broadcast medium access arbitration scheme. Like Token Bus it prevents collisions. Unlike TB, it is simple to implement, being based on three timers. In truth, it is a form of CSMA, with collision prevention; CSMA-CP. Each time the medium goes free, each station starts a timer. When the timer reaches a value peculiar to the station, it may use the medium with assurance that its transmissions will not suffer collision. These Arbitrated Access Opportunity (AAO) times are chosen so that each station can hear if stations with shorter timer settings have started transmitting. All timers are set to zero at all times the medium is busy. If all stations have passed up their opportunity to transmit, a Resynchronizing Time (RT) is reached, at which time all timers are restarted and the first station to reach its AAO is required to send something. Round-robin fairness can be assured by requiring each station to wait for the RT between its transmissions.

In the satellite case, the difference between successive timer settings is the propagation delay, plus the time to sense a free

medium, plus the R-T delay. For highest efficiency, the number of AAOs must be kept small. This would require some form of dynamic AAO assignment scheme, not covered by the ANSI standard. A dynamic AAO fully distributed assignment scheme shouldn't be very difficult to create, since all stations can determine which AAOs are being used. If AAOs which had not been used at least once in the previous minute were considered to be free, they could then be used by a station needing one. Of course the first transmission claiming an AAO could suffer collision, but the Op-CSMA scheme of backing off would quickly resolve the collision, and the losing station would then seek another free AAO. This collision would be between joining stations, not stations already "possessing" an AAO. The winning station would then have a collision-free AAO for further use. This is no worse than Token Bus, where stations wishing to join the token passing logical ring may suffer collisions from similar stations. Examine the accompanying figures to observe the advantages of limiting the number of AAOs to perhaps eight.

COMPARISON OF PERFORMANCE

The accompanying figures give a general picture of the available throughput of the various schemes, as a percentage of raw bit rate. Table 1 gives similar information for the Token Bus and LDDI schemes.

Channel Stability

When offered load increases, some access arbitration schemes become unstable (they lock up). Each time a packet is damaged by a collision it must be sent again, doubling the time on the channel. As offered load increases, collisions are more likely, and even more load is created by the repeats; soon all useful throughput ceases and the channel is fully occupied by the repeats. This phenomenon limits the useful throughput on ALOHA, Slotted ALOHA, and most CSMA schemes. The peaks of the curves in Figure 2, are at the maximum values of offered load that can be accomodated without instability. Non-persistent CSMA can be seen to be able to accomodate a ten-times overload, and is thus the most attractive of these schemes without collision detection.

Token Bus and LDDI (CSMA-CP) prevent collisions, and thus are unconditionally stable at all offered loads.

Receive-Transmit Switching Time

The various parts of Figure 1 illustrate that increased delay between the last time the channel can be observed by the receiver, and the time that the transmitter output commences reduces throughput in all but ALOHA (which doesn't listen). Even Token Bus is affected, since the station which receives the token must go from receive to transmit to use it or pass it on.

Data Rate

In all schemes considered, a net increase in data transfered can be achieved by using 1200 bits per second instead of 400 bits per second. The increase is exactly proportional in ALOHA, and less in Token Bus, Op-CSMA and CSMA-CP. The numerical values for TB and CSMA-CP are given in Table 1.

RECOMMENDED MEDIUM ACCESS SCHEMES

Table 2 presents a feature comparison of candidate access schemes.

Interim Arbitration Scheme

In the interim, use of ALOHA is recommended. The highest possible data rate should be used, so that offered traffic is the smallest possible fraction of the channel capacity. In case of packet loss (through collision), a large backoff time should be used to spread load as much as tolerable. Backoff times should be randomized to avoid lock-step collisions between retries.

Rejected Improved Schemes

There is a desire to improve on the throughput of ALOHA, within the practical means of radio amateurs. In view of the very substantial complexity of Token Bus, its use is not recommended, at least until an integrated circuit performing most of the functions, including token restoration after loss, and inclusion of new stations, is available inexpensively. One should consider the foreign availability of complex chips of this sort before mandating their use.

LDDI (CSMA-CP) can give greater throughput than non-persistent CSMA under some conditions. The dynamic AAO arbitration scheme described above requires some additional complexity, though considerably less than Token Bus.

Slotted ALOHA gives fairly good performance with maximum-length packets, but fixed-length packets are unlikely in this application. It also requires accurate time synchronization between all users of the channel.

Recommended Improved Scheme

For these reasons the use of non-persistent CSMA, with 1200 bit per second transmission, is recommended. Reducing Receive-to-Transmit switching time should be given emphasis. The backoff timers should only run when the medium is free. It is further recommended that substantial effort be directed to speeding the decay of transmitter output at turn-off.

Inclusion of Listen-While-Talk facilities to allow collision detection and transmission truncation should be encouraged. This will allow stations to tell if they have successfully captured the channel (after about 400 bits have been transmitted at 1200 bits per second). When this has happened, the station should send all waiting traffic without releasing the channel. Efficiency is greatly increased if a great deal of information can be sent for each successful medium arbitration.

REFERENCES

[KLE75] Leonard Kleinrock and Tobagi, F., Random access techniques for data transmission over packet-switched radio channels, Proc. Nat. Computer Conf., 1975, pp 187-201.

[SHE78] Richard H. Sherman, Gable, MG, McClure,G., Concepts, strategies for local data nrtwork architectures., Data Communications, July 1978, pp 39-49.

TABLE 1

BITS PER SECOND

Throughput if Sending Stations Average stated Size

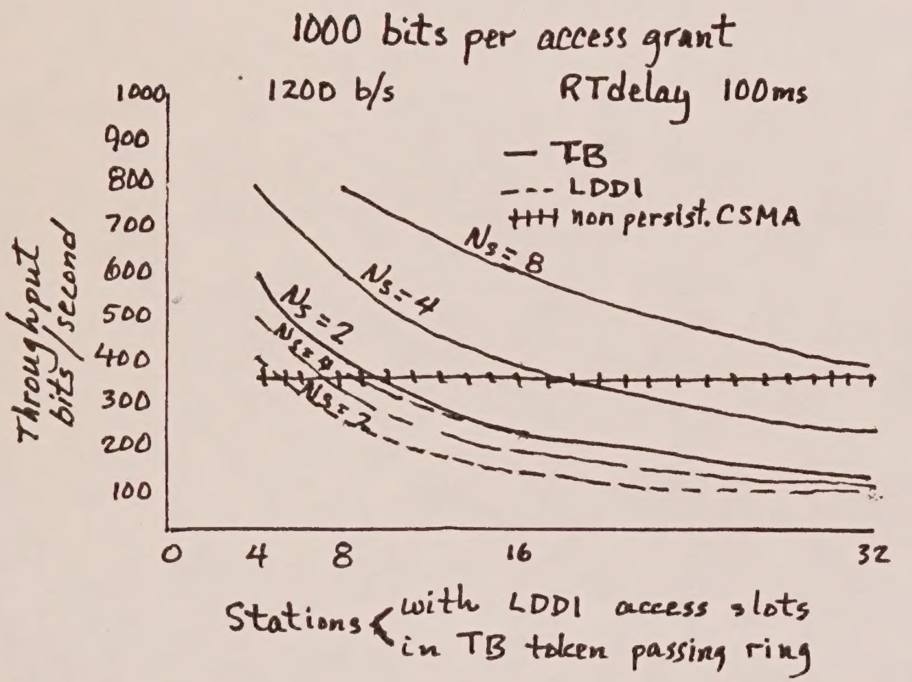
Stations		TR	1000 BITS PER XMISSION						2000 BITS PER XMISSION					
			400 Bd			1200 Bd			400 Bd			1200 Bd		
Sndg	Tot	Dly	CSMA	TB	LD	CSMA	TB	LD	CSMA	TB	LD	CSMA	TB	LD
2.	4.	.05	200.	276.	254.	410.	617.	440.	250.	327.	311.	515.	815.	644.
4.	4.	.05	200.	327.	282.	410.	815.	534.	250.	360.	331.	515.	970.	739.
2.	8.	.05	200.	211.	192.	410.	415.	281.	250.	276.	259.	515.	617.	456.
4.	8.	.05	200.	276.	222.	410.	617.	353.	250.	327.	286.	515.	815.	545.
8.	8.	.05	200.	327.	242.	410.	815.	404.	250.	360.	301.	515.	970.	605.
2.	16.	.05	200.	143.	129.	410.	251.	164.	250.	211.	195.	515.	415.	288.
4.	16.	.05	200.	211.	156.	410.	415.	210.	250.	276.	224.	515.	617.	358.
8.	16.	.05	200.	276.	174.	410.	617.	245.	250.	327.	243.	515.	815.	408.
16.	16.	.05	200.	327.	185.	410.	815.	268.	250.	360.	253.	515.	970.	438.
2.	32.	.05	200.	87.	78.	410.	140.	89.	250.	143.	130.	515.	251.	166.
4.	32.	.05	200.	143.	97.	410.	251.	116.	250.	211.	157.	515.	415.	212.
8.	32.	.05	200.	211.	112.	410.	415.	137.	250.	276.	175.	515.	617.	247.
16.	32.	.05	200.	276.	121.	410.	617.	151.	250.	327.	186.	515.	815.	269.
32.	32.	.05	200.	327.	126.	410.	815.	159.	250.	360.	191.	515.	970.	281.
2.	4.	.10	190.	269.	240.	360.	581.	400.	220.	321.	300.	470.	783.	600.
4.	4.	.10	190.	321.	270.	360.	783.	491.	220.	356.	322.	470.	947.	697.
2.	8.	.10	190.	202.	177.	360.	383.	251.	220.	269.	246.	470.	581.	416.
4.	8.	.10	190.	269.	208.	360.	581.	318.	220.	321.	274.	470.	783.	503.
8.	8.	.10	190.	321.	227.	360.	783.	366.	220.	356.	290.	470.	947.	561.
2.	16.	.10	190.	135.	116.	360.	228.	144.	220.	202.	180.	470.	383.	257.
4.	16.	.10	190.	202.	142.	360.	383.	186.	220.	269.	210.	470.	581.	323.
8.	16.	.10	190.	269.	160.	360.	581.	218.	220.	321.	229.	470.	783.	369.
16.	16.	.10	190.	321.	171.	360.	783.	239.	220.	356.	239.	470.	947.	398.
2.	32.	.10	190.	81.	69.	360.	126.	78.	220.	135.	117.	470.	228.	146.
4.	32.	.10	190.	135.	87.	360.	228.	102.	220.	202.	143.	470.	383.	188.
8.	32.	.10	190.	202.	101.	360.	383.	121.	220.	269.	161.	470.	581.	219.
16.	32.	.10	190.	269.	109.	360.	581.	133.	220.	321.	171.	470.	783.	240.
32.	32.	.10	190.	321.	114.	360.	783.	140.	220.	356.	177.	470.	947.	251.
2.	4.	.20	170.	255.	217.	340.	520.	339.	210.	311.	281.	430.	726.	529.
4.	4.	.20	170.	311.	248.	340.	726.	424.	210.	350.	306.	430.	905.	626.
2.	8.	.20	170.	187.	154.	340.	332.	207.	210.	255.	222.	430.	520.	353.
4.	8.	.20	170.	255.	184.	340.	520.	265.	210.	311.	252.	430.	726.	434.
8.	8.	.20	170.	311.	204.	340.	726.	308.	210.	350.	270.	430.	905.	491.
2.	16.	.20	170.	122.	98.	340.	193.	116.	210.	187.	157.	430.	332.	212.
4.	16.	.20	170.	187.	121.	340.	332.	152.	210.	255.	186.	430.	520.	269.
8.	16.	.20	170.	255.	138.	340.	520.	179.	210.	311.	205.	430.	726.	311.
16.	16.	.20	170.	311.	148.	340.	726.	196.	210.	350.	216.	430.	905.	337.
2.	32.	.20	170.	72.	56.	340.	105.	62.	210.	122.	99.	430.	193.	118.
4.	32.	.20	170.	122.	72.	340.	193.	82.	210.	187.	122.	430.	332.	153.
8.	32.	.20	170.	187.	84.	340.	332.	97.	210.	255.	138.	430.	520.	180.
16.	32.	.20	170.	255.	91.	340.	520.	107.	210.	311.	148.	430.	726.	197.
32.	32.	.20	170.	311.	95.	340.	726.	113.	210.	350.	154.	430.	905.	207.
2.	4.	.40	145.	231.	181.	190.	431.	260.	195.	293.	250.	380.	634.	427.
4.	4.	.40	145.	293.	214.	190.	634.	332.	195.	338.	279.	380.	830.	520.
2.	8.	.40	145.	163.	122.	190.	262.	153.	195.	231.	187.	380.	431.	272.
4.	8.	.40	145.	231.	150.	190.	431.	199.	195.	293.	218.	380.	634.	342.
8.	8.	.40	145.	293.	169.	190.	634.	234.	195.	338.	237.	380.	830.	392.
2.	16.	.40	145.	102.	74.	190.	147.	84.	195.	163.	125.	380.	262.	157.
4.	16.	.40	145.	163.	93.	190.	262.	111.	195.	231.	151.	380.	431.	203.
8.	16.	.40	145.	231.	108.	190.	431.	131.	195.	293.	170.	380.	634.	237.
16.	16.	.40	145.	293.	117.	190.	634.	145.	195.	338.	181.	380.	830.	258.
2.	32.	.40	145.	59.	41.	190.	78.	44.	195.	102.	75.	380.	147.	85.
4.	32.	.40	145.	102.	53.	190.	147.	59.	195.	163.	94.	380.	262.	112.
8.	32.	.40	145.	163.	63.	190.	262.	70.	195.	231.	108.	380.	431.	132.
16.	32.	.40	145.	231.	68.	190.	431.	77.	195.	293.	117.	380.	634.	145.
32.	32.	.40	145.	293.	72.	190.	634.	82.	195.	338.	122.	380.	830.	153.

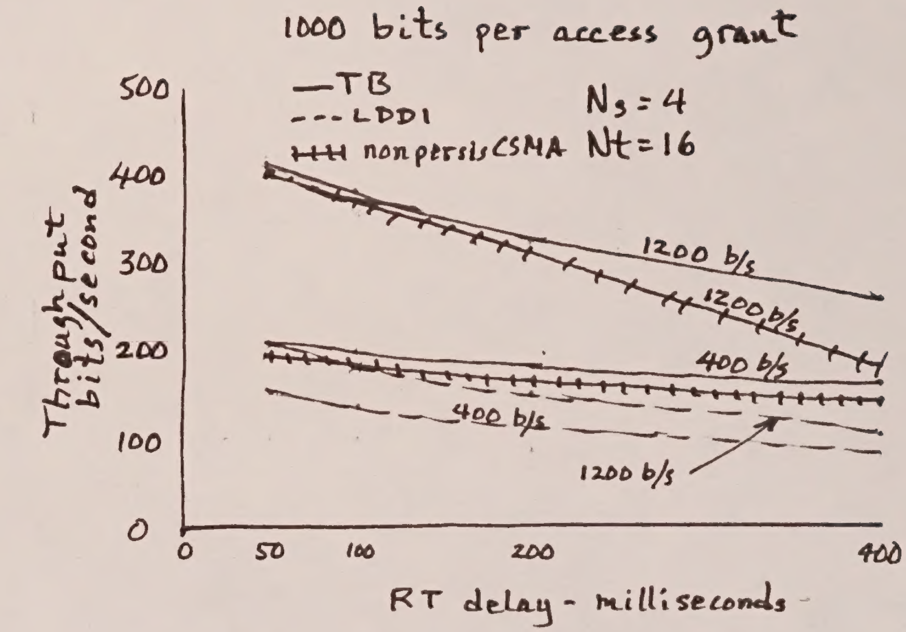
TABLE 2

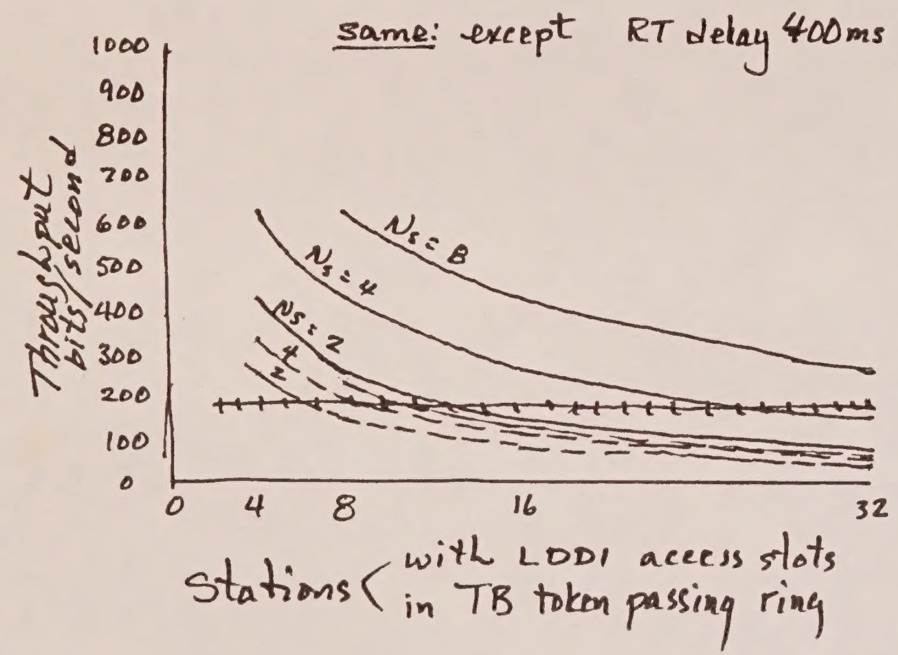
Characteristic	ALOHA	Slotted ALOHA	CSMA p=0	CSMA p=0,CD	CSMA CP(LDDI)	IEEE Token-Bus
Complexity						
rf equipment	simple	simple	modest	duplex	modest	simple
digital eqpt	simple	good clock	slight	modest	modest	medium
software	simple	simple	slight	modest	modest**	great
Throughput, RT delays of 100 to 400 ms, 4 to 8 stations						
1000 bit packets						
at 400 bps	17%	<34%*	35-45%	45-55%	30-55%	40-80%
at 1200 bps	17%	<34%	25-35%	30-40%	12-30%	22-60%
2000 bit packets						
at 400 bps	17%	<34%	50-60%	65-75%	47-80%	58-90%
at 1200 bps	17%	<34%	35-45%	45-55%	23-60%	36-80%
Throughput, RT delays of 100 to 400 ms, 16 to 32 stations						
1000 bit packets						
at 400 bps	17%	<34%*	35-45%	45-55%	10-43%	15-80%
at 1200 bps	17%	<34%	25-35%	30-40%	4-20%	6-65%
2000 bit packets						
at 400 bps	17%	<34%	50-60%	65-75%	19-60%	25-89%
at 1200 bps	17%	<34%	35-45%	45-55%	7-33%	12-79%
Stability						
offered load at which channel becomes unstable	17%	<34%*	~1,000%	>10,000%	always stable	always stable

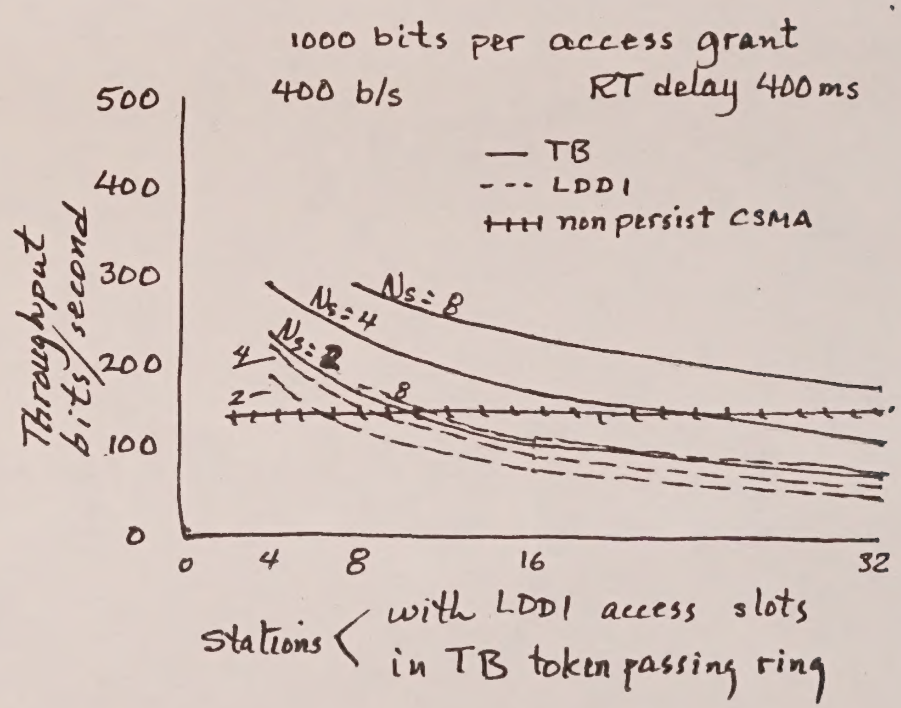
* If the packet does not fully occupy a slot, throughput will be smaller.
** Moderate complexity if dynamic AAO arbitration is done in software.

THROUGHPUT COMPARISON
— with 260 ms propagation delay









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